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MEMORANDUM

Subject: Progress Report 007
Chaotic LIDAR for Naval Applications: FY12 Q3 Progress Report (4/1/2012– 6/30/2012)

This document provides a progress report on the project "Chaotic LIDAR for Naval Applications" covering the period of 4/1/2012– 6/30/2012.

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III. Work Performed

During the summer, I experimented with doubling an IR laser to green. I then amplified the chaotic lidar source signal to levels high enough for doubling. I also modified the source laser, and experimented with source variations to produce other signals of interest.

A. Frequency Doubling: IR to Green

I used an IR source, free space optics, and a PPKTP crystal to experimentally determine the best optical configuration for frequency doubling. The source was a 1 W continuous-wave (CW) laser, and the PPKTP was a temperature controlled nonlinear crystal measuring 0.5 x 0.5 x 20 mm, which proved to be very sensitive to alignment relative to the incoming beam. Efficiencies of 0.8% per W were specified, but the results proved to exceed this expectation.

The small aperature and relatively long length of the crystal suggested a long, stretched hyperbola would be the best shape for the incoming beam. It was unknown whether filling the crystal evenly or maximizing power density in the crystal would be the more effective approach. By trying narrow and wide beams, and sharp and gradual focuses, it became clear that a wide beam and a gradual focus were preferable. Thus I expanded the ~1 mm beam from the laser to a full 15 mm, allowing a tight beam width at the focus, and then used a 300 mm lens to focus the beam, ensuring a very gradual focus. This proved to be effective, and with careful 6-DOF micrometer positioning of the lens, efficient frequency doubling was achieved. About 400 mW of IR light entered the crystal; 2.5 mW of green was outputted, for a conversion efficiency of 0.6%, or 1.5% per W.

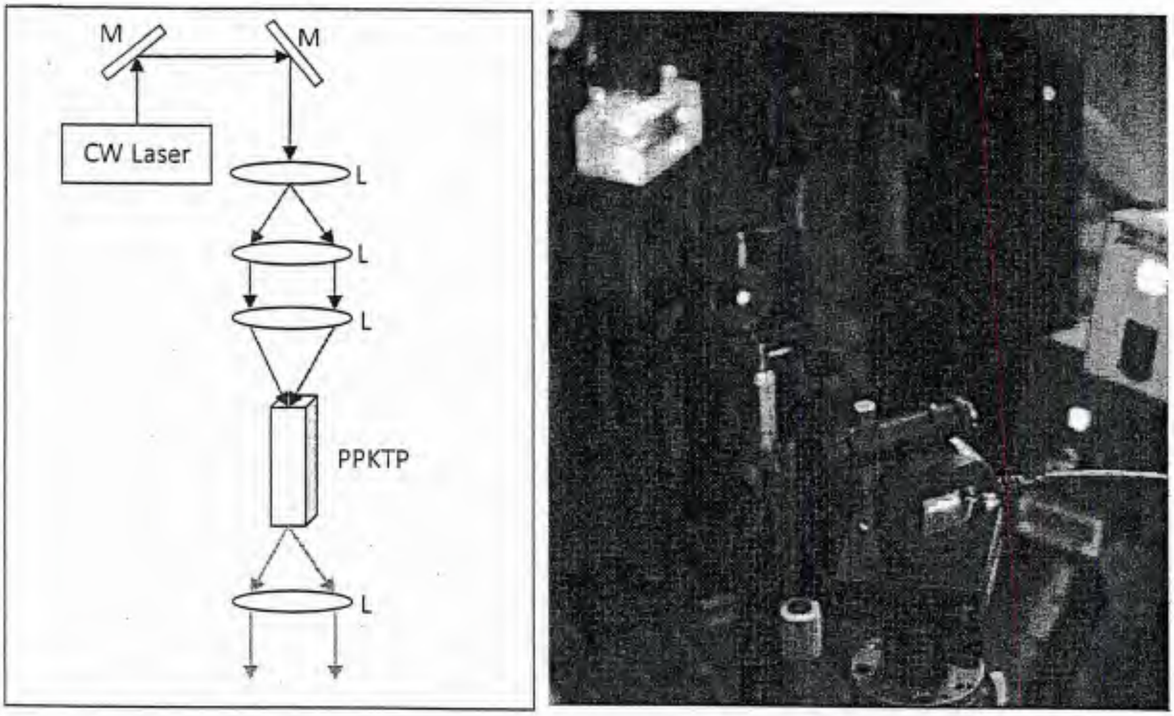

Fig 1. Frequency doubling from IR to green. Left: Block diagram of frequency doubling scheme, showing beam expanding and then focusing on the crystal, which changes the IR (red) to green light. Right: Photo of doubling setup; invisible IR light enters and visible green light exits crystal. (M: Mirror; L: Lens; PPKTP: Periodically Poled KTP crystal)

B. Source Laser and Preamplifier

Having demonstrated that IR doubling to green could be performed with IR powers of at least 1 W, I then set out to amplify the source laser. Simulations performed during the spring at Clarkson University suggested that a 10 mW laser could be boosted by a preamplifier stage to nearly 200 mW (a 13 dB gain) without corrupting the signal, and that a second stage could drive the signal as high as 12 W (a 17 dB gain). Each stage required pump lasers, a pump/signal combiner, and a length of active fiber. The pump lasers would provide raw power; the combiner would pass the pump and the signal light to the active fiber; and the active ytterbium fiber would transfer the pump energy to the signal itself, amplifying the signal.

The source laser's output power proved to be far lower than expected; while it was initially producing 18 mW, a necessary filter reduced its output to just 1 mW. When this signal was run into the preamplifier, the signal was amplified to just 20 mW (13 dB) before it became highly corrupted with spontaneous emission (ASE). This indicated that the source output was too low and so a reconfiguration was necessary. This reconfiguration was very successful, resulting in 60 mW output, and this enabled amplification to 180 mW (pump-limited) by the preamplifier.

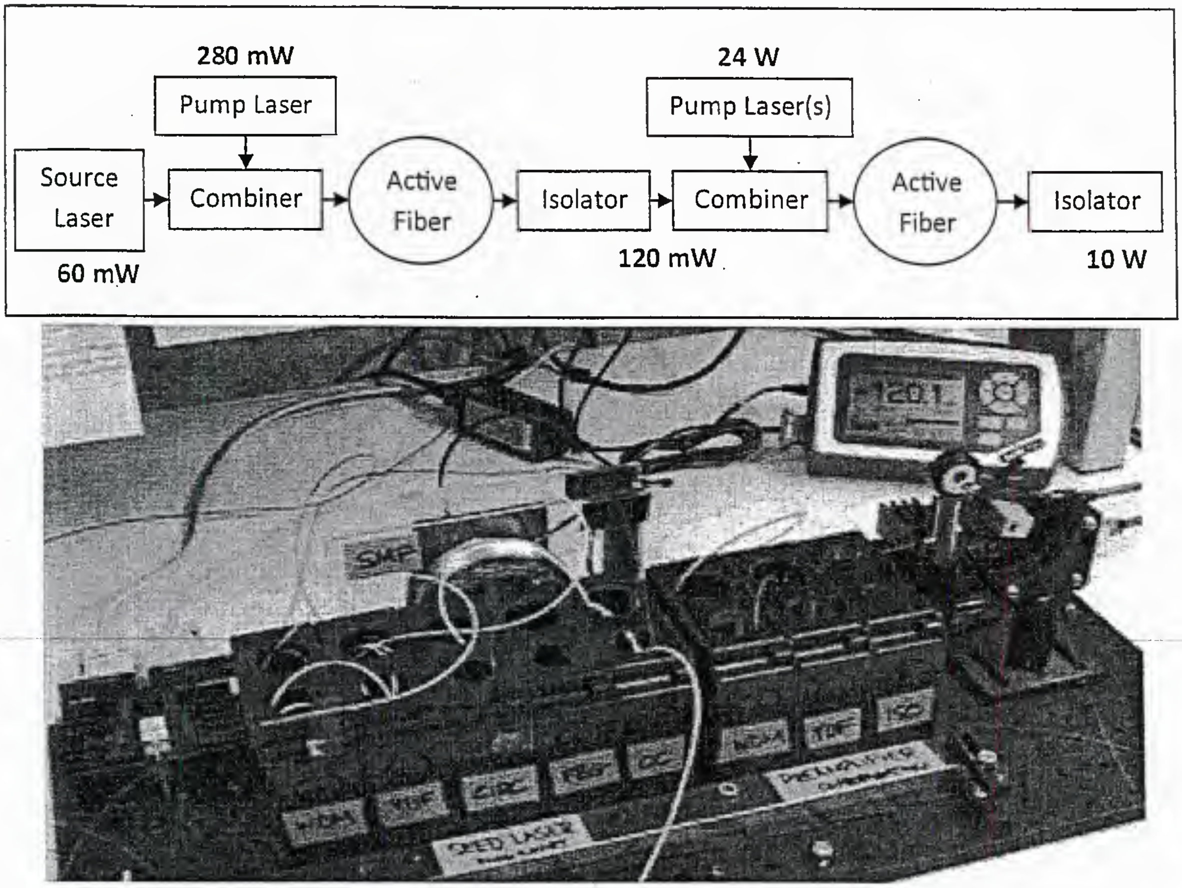

Fig 2. Amplification of IR signal. Top: Block diagram of amplification stages, showing source laser signal being increased by two combiner/active fiber gain stages. Bottom: Photo of actual seed laser and preamplifier, showing output power of 120 mW after isolator, in family with simulation predictions.

Passing into the second amplifier stage, the signal saw heavy insertion losses in an isolator, a mode-matching splice, and a combiner. Thus, the signal to the gain amplifier's active fiber was about 80 mW. Meanwhile, a multimode pump laser was fed into the active fiber; a total of 32 W pump power was available for this second stage. Pump transfer through the combiner was efficient at ~95%. However, when the active fiber was connected, the pump laser, which had been performing well for days, suddenly failed, and proved irreversibly damaged. Upon investigation and consultation with industry experts, I concluded that this failure was due to a back-reflection off the fiber-to-free-space interface, and that an isolator was necessary to prevent such back reflections from propagating back through the active fiber and being amplified to dangerous levels. Thus the gain amplifier was redesigned and reconstructed.

C. Derivative Sources

While the chaotic fiber laser originally developed at Clarkson will be useful for high-resolution ranging by itself, it also presents exciting opportunities to develop other sources that will be tailored for specific applications. This is because the source laser includes frequency content across a huge bandwidth, in the form of thousands of tightly spaced modes.

Experimentation using an RF signal source and a Mach-Zender Modulator (MZM) in a fiber ring laser cavity proved that any one of these modes can be caused to dominate the others by modulating the cavity loss at the desired frequency. Thus, an adaptive signal source can be developed, where the modulation frequency can be controlled and instantly changed in response to water conditions. This source would be very high quality, where nearly all the energy would be in the lasing mode, and that mode would be a pure tone with very low bandwidth (low-bandwidth modes are characteristic of long resonator cavities such as that in the source laser). The proof-of-concept experiments were successful and development will be pursued.

I also experimented with pulsing the source laser's pump while keeping the amplifier pumps constant, in an effort to create a high power pulsed signal that would have very high peak powers. This is desirable for increasing frequency doubling efficiency, and may also be helpful in reducing ambiguity in range resolution. The proof-of-concept experiments performed at Pax River were inconclusive; there was some increase in peak power, but it was not along expectations, so further investigation will be necessary.

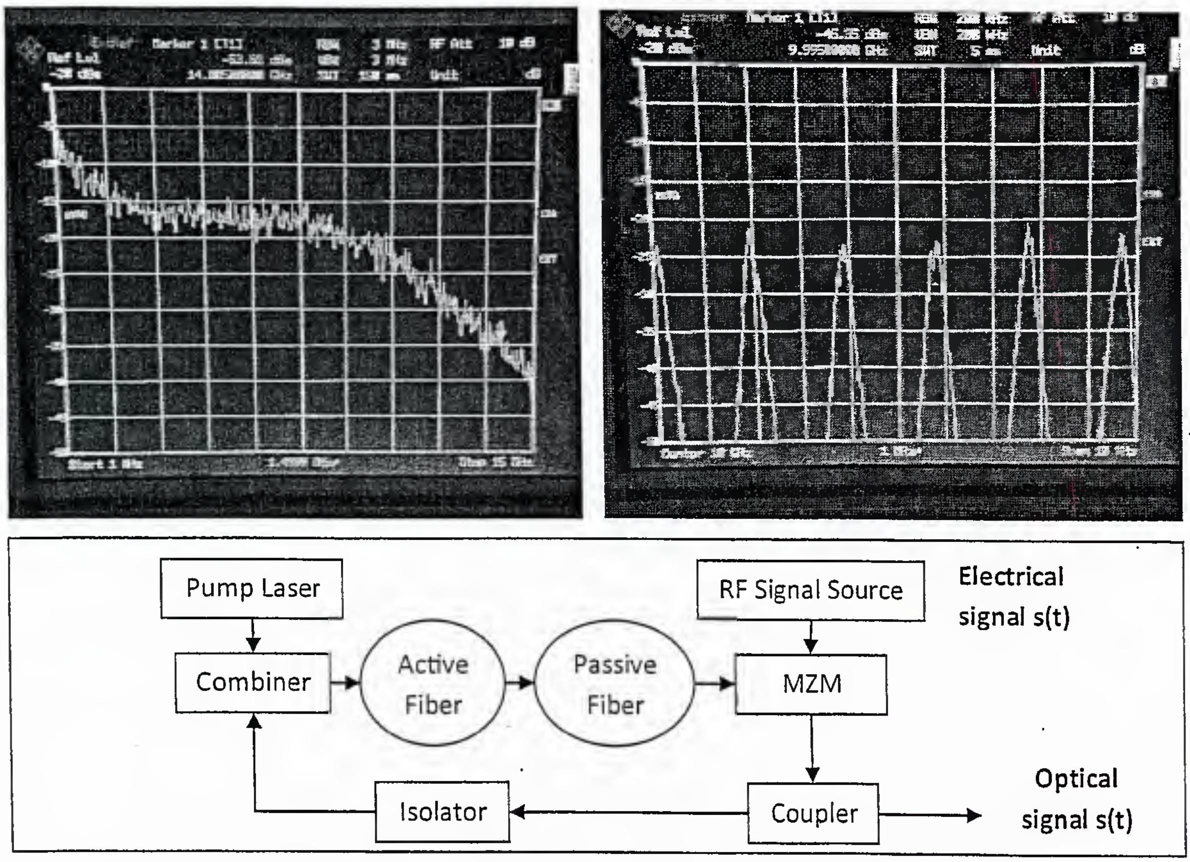

Fig 3. Many-mode signal source. Top left: Full spectrum of laser modulation frequencies, showing content from 0 to 15 GHz. Top right: Close up of standing modes; thousands of these modes constitute the full 15 GHz spectrum. Bottom: Block diagram of proof-of-concept laser that forces a single arbitrary frequency mode to dominate. A high-quality, instantaneously changeable signal source is created. (MZM: Mach-Zender Modulator)